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Wireless Power Transfer Due to Strongly Coupled Magnetic Resonance

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Abstract: Our project titled "Wireless Power Transfer via Strongly Coupled Magnetic Resonances" .During the course of this research; we investigated the need and usefulness of wireless power transmission and the feasibility of using magnetic inductive coupling as the means for wireless power transmission. The paper will outline our design process and the logical steps we took in the experimentation and design of our circuits. The first section of the document will explicitly illustrate the goals we set to accomplish during the allotted time frame of three and a half weeks. With the complexity of the problem in mind and what we must accomplish, our team began research on the available means to transmit power without a physical connection. Existing techniques of wireless power transmission involving a pair of strongly magnetically coupled resonators allow transmission of tens of watts of power over a few meters. By introducing high Q L-C resonators, researchers are able to efficiently transfer power from one resonant transmitter to another resonant receiver. However, efficiency greatly deteriorates upon adding more receivers to the strongly coupled system because of the interactions between multiple coupled resonators. Implementation of a wireless power transmission system, we transmit near field wireless power with a goal not to maximize the distance of power transmission, but rather, to power devices on a surface. Our objective is to allow the introduction of numerous non- resonant pick up coils to enable multiple devices to be powered on the surface at once with only one resonant-transmitter with the goal of powering multiple devices with a single transmitter; we design a system that drives a primary inductor that is coupled with a high Q L-C secondary resonator.

Keywords: Wireless Power, Magnetic Resonance Imaging, Magnetic Coupling.

I. INTRODUCTION

The first visions of wireless power transmission came from nikola tesla in the early 20th century; his biggest project involved the wardenclyffet tower. Although the transmitting tower could be used for wireless communications, it was constructed with the intention to transmit wireless power. In tesla's power transmission system, he hypothesized the earth to be a giant charged sphere that could be driven at its resonant frequency and that he could close the circuit using giant electric fields in the earth's ionosphere, much of his research on wireless power involved radioactive electro-magnetic waves that are practical for transferring information but pose immense difficulties for wireless power transfer for two reasons. Firstly, unidirectional radiation is very power inefficient. Secondly, if we were to use unidirectional radiation instead, we would require a direct line of sight and complicated tracking mechanisms. Although wireless power could have been developed lot earlier, there was never strong demand for it because of the lack of mobile electronic devices then. Commonplace mobile electronics today such as laptops and cell phones have caused a renewed interest in wireless power. In 2007, a group of researchers at mit achieved wireless power transfer, powering a light bulb of 60w over distances exceeding 2 meters with efficiency of around 40%. In their wireless power system, they use a pair of strongly magnetically coupled resonators, with a transmitter and a receiver forming a resonant pair. A lot of research has focused on a resonant transmitter and receiver pair to transfer power wirelessly. Such architecture has a highly efficient one to one coupling between the resonant transmitter and receiver. However, adding more receivers causes the efficiency of power transfer to deteriorate tremendously.

A. Motivation and Project Goals

The motivation for wireless power comes from wires being cumbersome and messy. With the large number of mobile electronics that we own today, there is a demand for convenience in managing their power supplies. Wireless communication has revolutionized the way we interact with communication devices. We also observe that while the techniques of strongly coupled magnetic resonances allow efficient power transfer between a pair of transmitter and receiver coils, efficiency greatly deteriorates upon adding more receivers to the strongly coupled system due to the interaction between multiple coupled resonators. In tightly coupled resonant wireless power transfer, we require a one to one correspondence between transmitter and receiver. This system then is not scalable for a large number of users with a large number of mobile devices because every single device has to have its own unique transmitter. A hypothetical conference room providing wireless power to laptop computers for twenty users will have to have 20 transmitters and each of the users will have to pre-tune their receivers to the right frequency. With this in mind, the goal of our work is to allow the powering of multiple devices with only one resonant transmitter through the introduction of numerous non-resonant pick up coils. We design these non-resonant pick up coils to power generic USB devices.

II. METHODOLOGY

In our power surface design, we deal with coupled rectangular coils. It is then useful to model the behavior of coupled rectangular coils using the physics behind inductive power transfer .Applying Bio-Savart's Law, it can be shown that the magnetic flux density at a point at a distance *r* from a straight conductor (Fig 1) making an angle of θ_1 with one end and an angle of θ_2 with the other

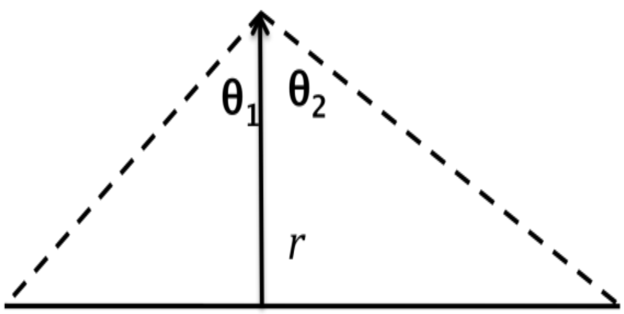

Fig 1: A point at a distance *r* from a straight conductor.

A.Operating Principles

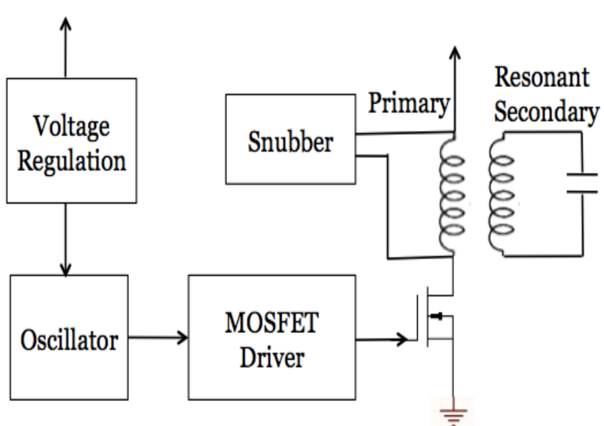

Fig 2: Block diagram of power surface transmitter.

end and having a current *I* flowing through the conductor is given by

$$B = \mu_0 I \sin\theta / 4\pi r \quad (1)$$

The principles of operation of our wireless transmission system are very similar to the surface based wireless power transmission system used for communication within robot swarms as shown in fig 2 .In a resonant system, the circulating current in the resonant coil is greater than the drive coil by the quality factor *Q*.

B. Wireless Power System Design

With all the necessary background research completed it became clear what basic design components the entire system would require. First we needed a method to design an oscillator, which would provide the carrier signal with which to transmit the power. Oscillators are not generally designed to deliver power, thus it was necessary to create a power amplifier to amplify the oscillating signal. The power amplifier would then transfer the output power to the transmission coil. Next, a receiver coil would be constructed to receive the transmitted power. However, the received power would have an alternating current, which is undesirable for powering a DC load (fig 3). The basic configuration of the design can be seen from table and image below.

TABLE I: THE BASIC CONFIGURATION OF THE DESIGN

Transmitting Coil	No of turns	1
	Diameter of each turn	60.32
	Diameter of copper tube	0.95
Receiving Coil	No of turns	1
	Diameter of each turn	60.32
	Diameter of copper tube	0.95
Transmitting Coil	No of turns	1
	Diameter of each turn	56.1
	Diameter of copper wire	0.23
Receiving coil	No of turns	2
	Diameter of each turn	44.6

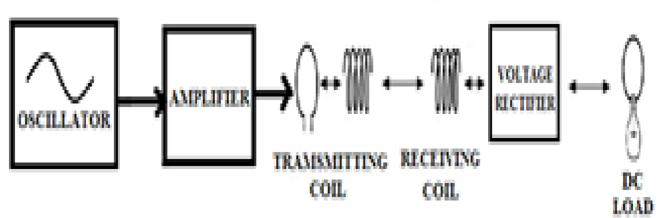

Fig 3: Circuit design.

III. COMPONENT DESCRIPTION

1. 12-0-12 Transformer (5 Amp)
2. Diode (In5402, Byv62e, In 4007)
3. Capacitor (4700 Micro Faraday, 0.44uf)
4. 7812 Voltage Regulator
5. Irf2807 Mosfet
6. Inductor 1000 Uhenry
7. 10v Zener Diode
8. Resistor (10k, 470 Ohm, 2.2 K)
9. 10 Mm Led
10. Inductive Coil (18 Turns)

A. Transformer Configurations

A 120 volt transformer with two wires in and two wires out is very simple. You hook up the two wires on the primary side, the 120V side, to a wall outlet and your output voltage is on the two wires coming from the secondary side (fig4).

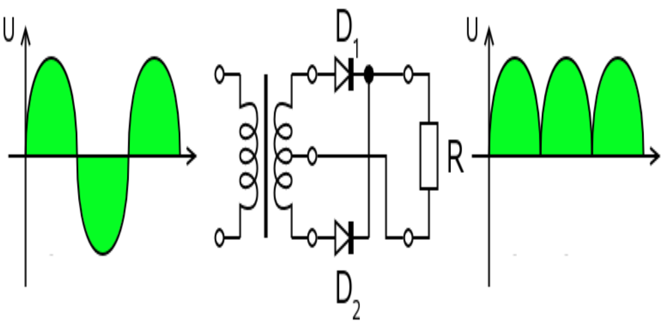

Fig.4: Transformer Configurations.

B. Diode

Diodes are used to convert AC into DC these are used as half wave rectifier or full wave rectifier. Three points must he kept in mind while using any type of diode (fig 5).

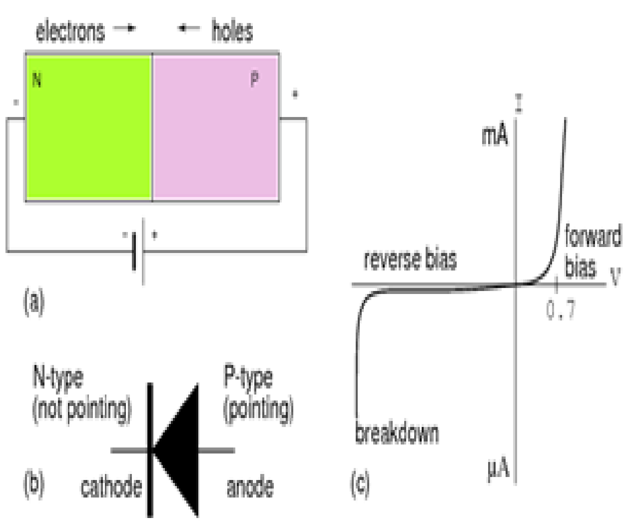

Fig 5: PN Junction diode.

1. Maximum forward current capacity
2. Maximum reverse voltage capacity
3. Maximum forward voltage capacity

C. Capacitors

A capacitor or condenser is a passive electronic component consisting of a pair of conductors separated by a dielectric. When a voltage potential difference exists between the conductors, an electric field is present in the dielectric. This field stores energy and produces a mechanical force between the plates. The effect is greatest between wide, flat, parallel, narrowly separated conductors as shown in fig 6 and 7.

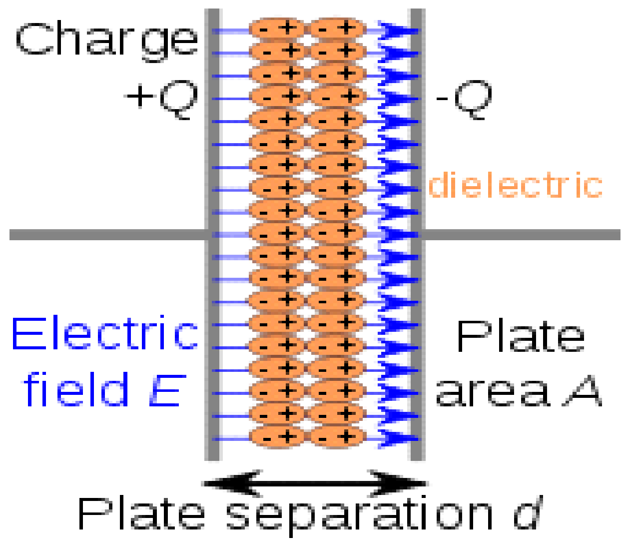

Fig.6: parallel plate capacitor.

D. Voltage Regulator 7805

Features:

- Output Current up to 1A.
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V.
- Thermal Overload Protection.
- Short Circuit Protection.
- Output Transistor Safe Operating Area Protection.

TABLE II: RATINGS OF THE VOLTAGE REGULATOR

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (KA78XX/A/R)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

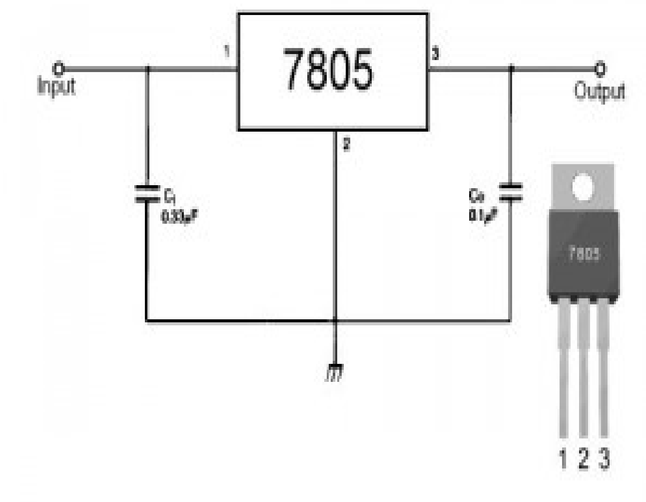

Fig.7: voltage regulator pin diagram.

E. Power Supply

Every electronics circuit runs on a power-source of some kind. This design is based around 4 main parts. A transformer (optional in case of DC-input voltage(fig 8)), a bridge rectifier, a smoothing capacitor and the LM78XX chip which contains a 'linear voltage regulator'. The design is split up in a part that concerns itself with transforming AC into DC and a part that explains just how to regulate the DC part with the LM78xx chip.

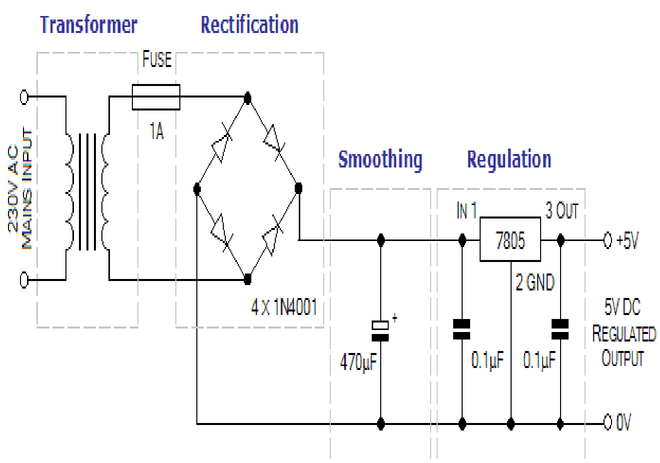

Fig.8: Schematic Diagram of Power Supply Circuitry.

F. Voltage Rectifir

In this project, a bridge rectifier is used because of its merits like good stability and full wave rectification. In positive half cycle only two diodes(1 set of parallel diodes) will conduct, in negative half cycle remaining two diodes will conduct and they will conduct only in forward bias only. Figure show for voltage rectification (fig 9):-

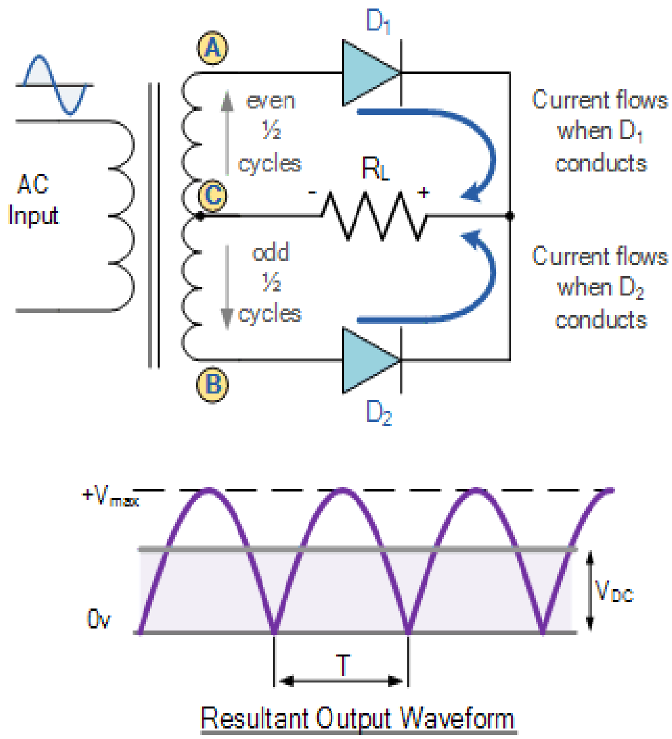

Fig.9: voltage rectification.

G. Smoothing

Smoothing of the output DC voltage up to the desired level is done by using electrolytic capacitor. Below fig 10 schematically explains it's working.

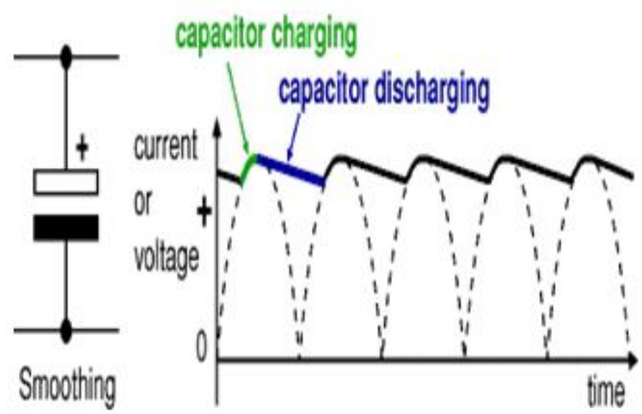

Fig.10: Working Of a Capacitor For The Purpose Of Smoothing.

IV. RESULTS AND MEASUREMENTS

At a distance of 21 cm between the two coils, we were able to transmit enough power to power a 3V LED. As the distance of separation between the coils was increased, the bulb got dimmer. It was evident from this simple experiment itself that the power transmitted was related to the distance of separation between the coils. To demonstrate the presence of evanescent waves being produced which transferred power from the transmitter coil to the receiver coil, we measured the voltage across the 3V LED bulb at varying distances and orientations. We took measurements starting at a distance of 0.5 m between the coils in 10 cm increments up to a distance of 2 m of separation. We found that the resonant frequency changed with distance due to the imperfect match in the resonant frequencies of our coils. The frequency was then adjusted to find the maximum output voltage at every measurement.

A. Final Project Picture

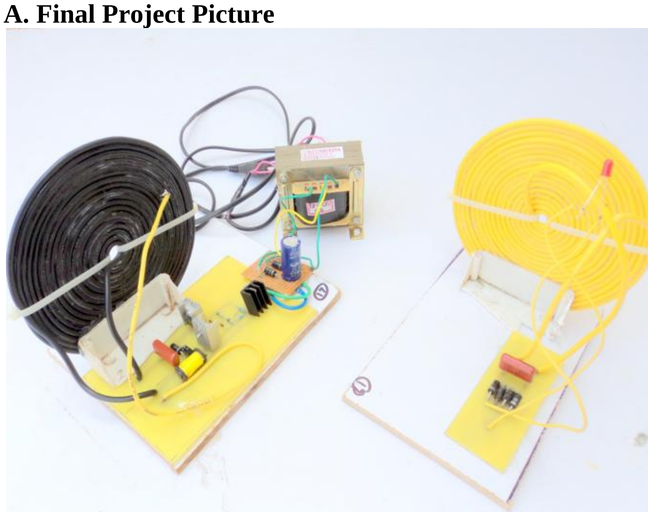

Fig.11: Final Project Picture.

V. CONCLUSION AND FUTURE WORK

We were able to design discrete components such as the relaxation oscillator, switch mode-power amplifier and a full bridge voltage rectifier for the system design process. We also managed to demonstrate evanescent waves by measuring exponential decay of voltage as an increase in distance between the transmitter and the receiver coils. There can be significant research work that can be done in the future of this research. Future work includes connecting the relaxation oscillator with the power amplifier using current amplifier chip for providing enough current to drive the gate of the MOSFET to drive the efficient class D H-Bridge power amplifier. Also, reduction in the size of the transmitting and receiving coils and utilizing the regulated signal to power a DC load could be something that could be worked in the future as a means to make this system feasible for practical applications.

Applications:

- For charging DC devices such as mobile phones, laptops etc.
- For instantaneous on-road charging of hybrid and pure-electric vehicles.
- Industrial manipulators.

VI. REFERENCES

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